Modelling residential smart energy schemes

Vashti Galpin

Laboratory for Foundations of Computer Science
School of Informatics, University of Edinburgh

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Collective Adaptive Systems

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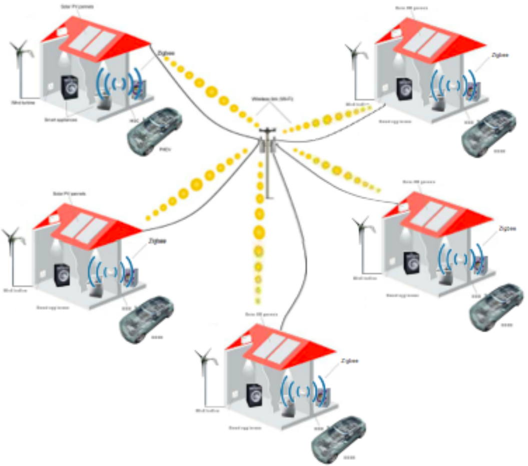
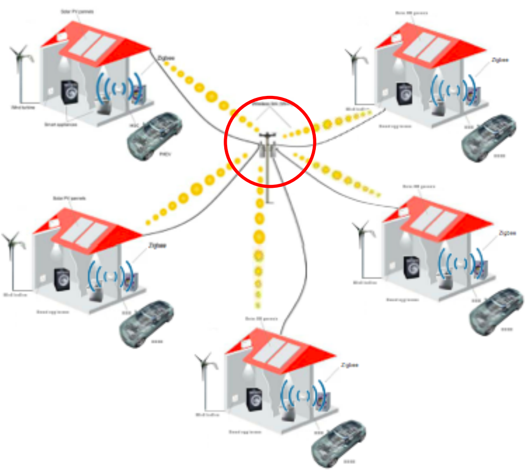
COOPERATION

Neighbourhood energy scheme



Oviedo *et al*, IEEE PES Transmission & Distribution Conference and Exposition, 2012
Oviedo *et al*, International Journal of Electrical Power & Energy Systems, 2014

Neighbourhood energy scheme



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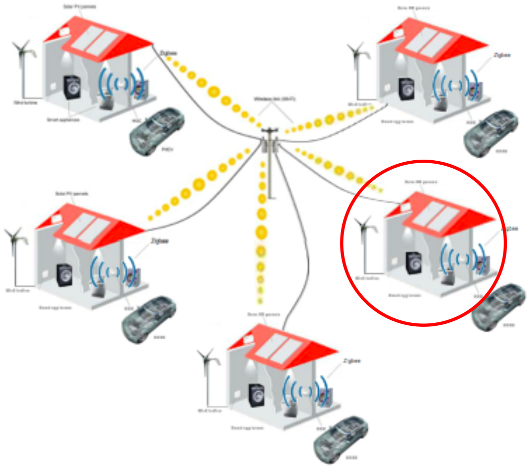

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Neighbourhood energy scheme

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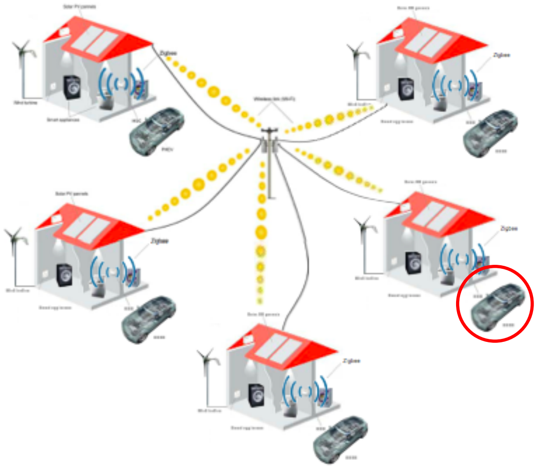

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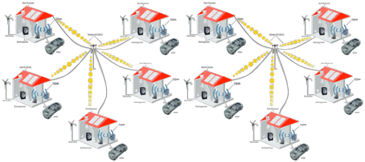
Suburb energy scheme



Suburb energy scheme

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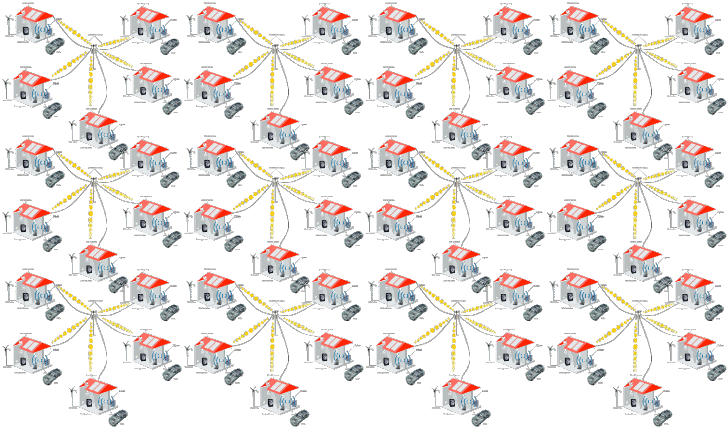
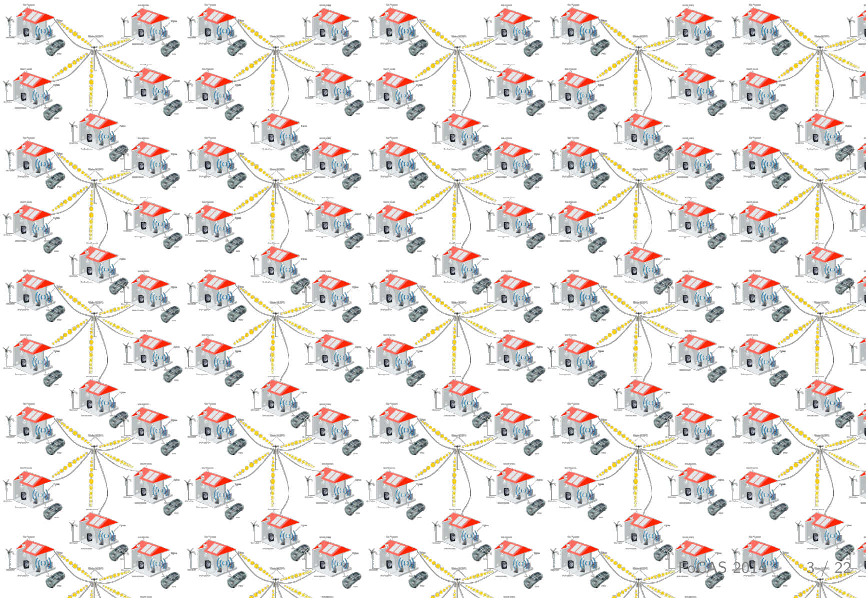


Suburb energy scheme



Suburb energy scheme

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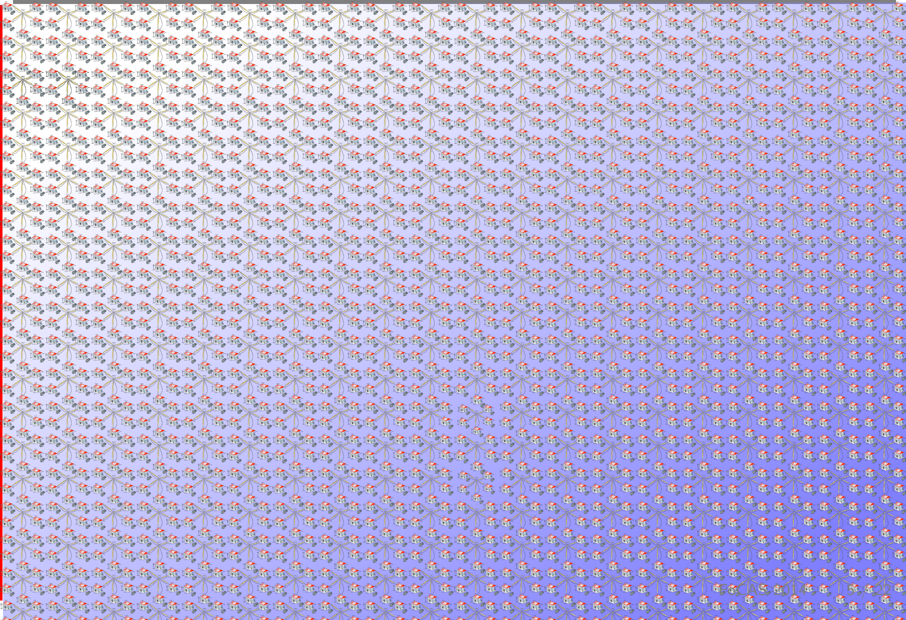
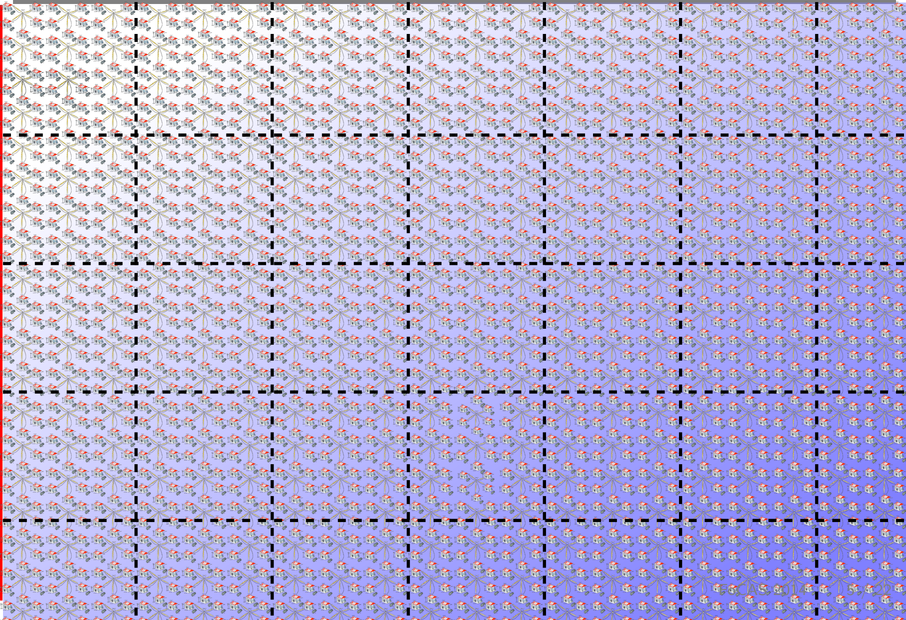
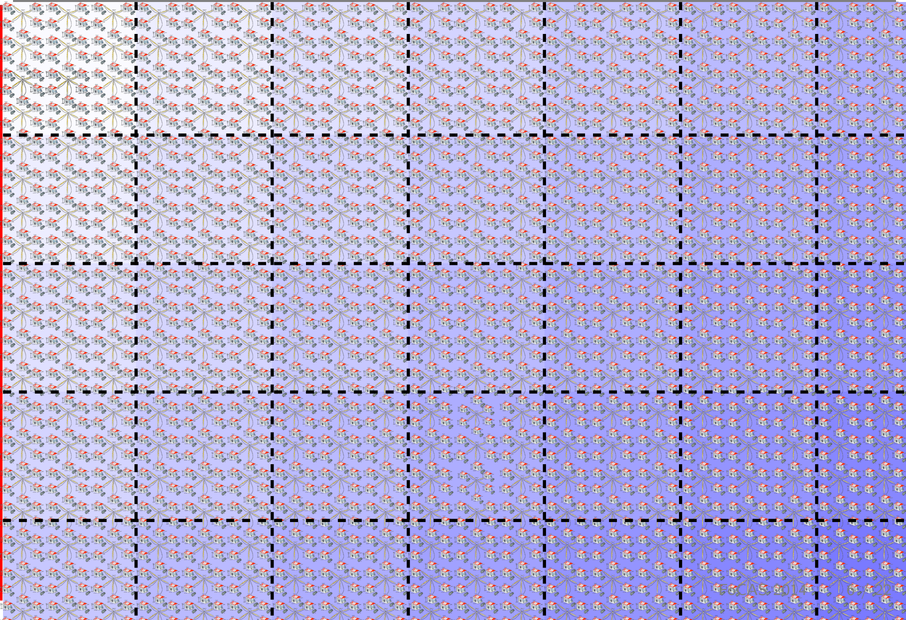


Suburb energy scheme



Suburb energy scheme



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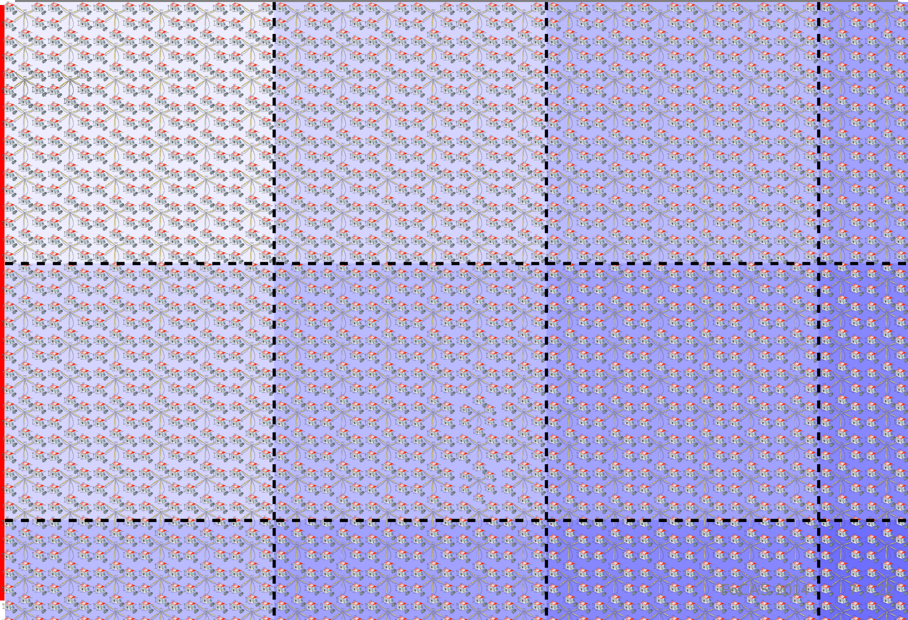

Outline

1. Motivation and goals
2. Stochastic HYPE
3. Prototype model
4. Results
5. Extensions
6. Conclusions

Motivation and goals

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Quantitative modelling of collective adaptive systems (CAS)

- Scalable, population-based quantitative dynamic modelling
- Abstraction and fluid and mean-field approximations
- Formal language for description of CAS
- Modelling to reason about existing and potential systems
- Case studies from smart transport and smart grids
- Spatial aspects are crucial to case studies
- Investigation of existing quantified spatial approaches
- Development of appropriate modelling techniques
- Design workflow for quantitative modelling of CAS

Motivation and goals (continued)

Residential smart grids

Local generation of renewable energy plus grid supply

- Collective: multiple households with various characteristics together with communication between them
- Adaptive: responds to information about prices and unused renewable energy, policies are necessary
- Prototype model to explore and understand features of scenario
- Use of an expressive formalism (stochastic HYPE) with an existing simulation tool (SimHyA)
- Spatial aspects in the case of multiple neighbourhoods
- Application of spatial moment closure techniques

Stochastic HYPE

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Stochastic hybrid process algebra

Continuous, stochastic and instantaneous behaviour

- Process algebra: small, elegant, formal language to describe concurrent behaviour with mathematical semantics
- Stochastic HYPE is very expressive, simulation for analysis
- Flows of energy are represented as continuous behaviour
- Availability of renewable energy and absence of vehicle can be expressed by stochastic durations
- Changes of policy and changes in energy flows can be captured through conditions for instantaneous events

Prototype model

- neighbourhood: four houses in a circle linked to neighbours
- household: wind turbine, plug-in hybrid electric vehicle (PHEV)
- electricity has three prices: peak, mid-peak, off-peak
- battery charging policy
  - if wind turbine generating then charge PHEV battery
  - if battery below threshold then charge from grid
  - if battery above threshold and not peak then charge from grid
- energy sharing policy
  - if wind turbine generating and battery is full or absent
    then offer energy to connected neighbour

Prototype model (continued)

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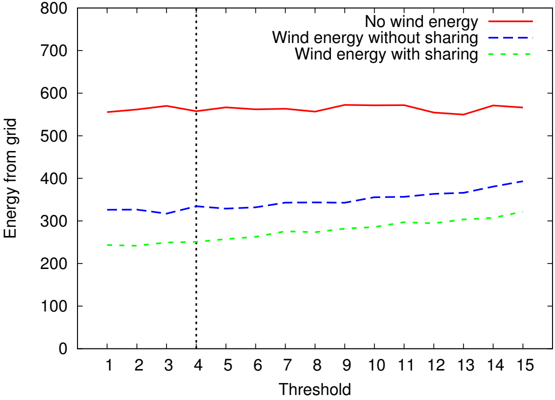
- weekday behaviour only
- wind: exponential distributions for presence and absence of sufficient wind to generate energy to match UK average
- departure of PHEV: exponentially distributed time after 7am
- return of PHEV: exponentially distributed time after 4pm
- distance travelled: exponential distribution with average 40 km
- battery parameters: from actual vehicle
- wind turbine parameters: from actual turbine

Experiments and results

- three experimental conditions, total cost and usage over 20 days
  - no generation of energy by wind
  - wind generation without sharing
  - wind generation with sharing
- efficiency measures
  - cost efficiency: ratio of savings to costs without renewables
  - energy efficiency: ratio of renewable energy to all energy
  - wind efficiency: ration of wind used to wind available
- results with battery threshold of 4 kWh for initial charge

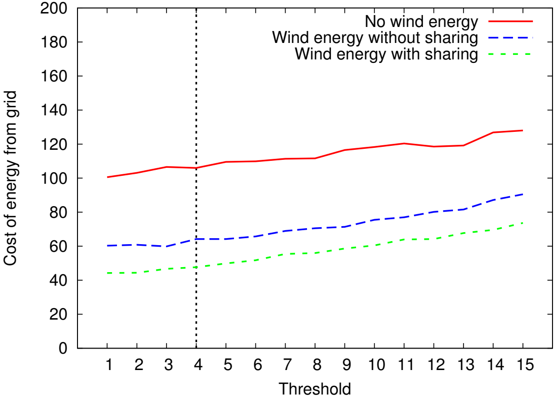
	no wind	no sharing	sharing
cost	£106.51	£64.19	£47.67
cost efficiency		40%	55%
energy efficiency		30%	38%
wind efficiency		48%	62%

Results: energy from grid



(average of 50 simulations of a 20-day period)

Results: cost of energy from grid



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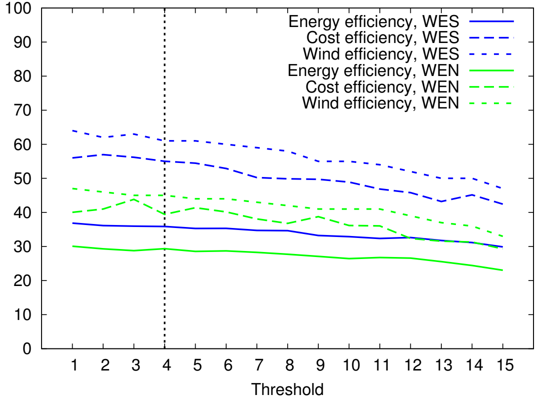

(average of 50 simulations of a 20-day period)

Extensions

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- addition of appliances to enable better use of renewables in household
- addition of household battery to enable better storage of renewables in household
- addition of photovoltaic panels to use solar energy
- limitation about number of batteries being charged at peak periods
- neighbourhood wind turbine rather than household wind turbines
- possibility of returning extra power to grid
- policies: first-come, first served or something else?

Extensions (continued)

- more formal treatment of various energy sources and storage

HR	household renewables
ND	household connection to neighbourhood distribution point
GR	neighbourhood connection to national grid
FS	household fixed storage
MS	household mobile storage
AP	household appliances
NR	neighbourhood renewables
NS	neighbourhood fixed storage
CN	connections to other neighbourhoods

Extensions (continued)

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- quantitative description of energy flows

	HR	ND	GR	FS	MS	AP
HR	X	[0,1]	[0,1]	[0,1]	[0,1]	[0,1]
ND	X	X	[0,1]	[0,1]	[0,1]	[0,1]
GR	X	X	X	[0,1]	[0,1]	{0,1}
FS	X	X	X	X	[0,1]	[0,1]
MS	X	X	X	X	X	[0,1]
AP	X	X	X	X	X	X

- separation of concerns: physical events versus policies
- scalable modelling: suburb of many neighbourhoods

Conclusion

- Prototype model of residential smart energy scheme
- Simulation to explore scenario and compare policies
- Going forward with extensions to the model
- Scalable model of many neighbourhoods with spatial variation
- Fluid, hybrid and system-of-systems techniques

Thank you